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# UTILIZATION OF MANGANIFEROUS IRON ORES

BY

T. L. JOSEPH, P. H. ROYSTER, and S. P. KINNEY

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# UTILIZATION OF MANGANIFEROUS IRON ORES

By T. L. Joseph, P. H. Royster, and S. P. Kinney

## INTRODUCTION

Manganese may be considered indispensable in all present steel-making processes. It is not only a superior deoxidizer but it adds desirable physical properties to the finished steel. Users of manganese fully appreciate the situation in regard to domestic reserves and realize that the United States is dependent upon imports of high-grade manganese ore and of ferromanganese. Information compiled by the Mining and Metallurgical Society of America[1] indicates that the reserves of ore, containing 35 per cent manganese, would supply the domestic demand for about three years at the present rate of steel making. This situation suggests careful consideration of low-grade ores with a view to conserving a limited and vital resource.

The North Central station of the Bureau of Mines and the University of Minnesota School of Mines experiment station have undertaken joint research on the utilization of manganiferous iron ores. The investigation may be divided as follows:

1. The use of manganiferous iron ores with respect to effect on blast-furnace operation; effect of high-manganese pig iron on the quality of steel; decrease in ferromanganese by the use of high-manganese pig iron; and desulphurization of steel through the presence of manganese.

2. The utilization of manganiferous iron ores in the production of ferromanganese.

3. The use of 6 to 10 per cent manganese alloys as additions to steels containing more than 0.3 per cent carbon.

## ACKNOWLEDGMENTS

Acknowledgments are due W. F. Holbrook, F. A. Hartgen, and Carl E. Wood for their assistance in these investigations. The writers are indebted to Harold J. Neyer and Fraser B. McKenzie,

[1] Mining and Metallurgical Society of America, Report of Subcommittee on Manganese: Bull. 168, March, 1924.



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two practical furnacemen, whose advice and assistance contributed in a large measure to the operation of the experimental furnace. The interest and cooperation of D. A. Lyon, chief metallurgist of the Bureau of Mines, and W. R. Appleby, dean of the School of Mines of the University of Minnesota, are gratefully acknowledged.

## PRESENT USE OF MANGANIFEROUS IRON ORES

Manganiferous iron ores, differing in composition, occur in several districts in the United States. The Cuyuna district of central Minnesota, however, contains the most extensive deposits as yet discovered; they have also the advantage of proximity to the Great Lakes. These ores are now finding an increasing market as sulphur scavengers in the blast furnace and for producing high-manganese pig iron. It has been claimed that a superior quality of steel can be made from high-manganese pig. There is evidence that additions of ferromanganese are less when high-manganese pig is used. Table 1, by C. L. Kinney, jr.,[2] shows the effect of residual manganese on additions of manganese made in the ladle:

TABLE 1.—*Effect of residual manganese on manganese added in ladle*

| Type of charge | Residual Mn, per cent | Tons ingot | Weight Mn in bath, pounds | Weight Mn required, pounds | Theoretical added Mn, pounds | Actual pounds Mn in ladle | | Pounds 80 per cent FeMn |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Tons | Heat | |
| Scrap | 0.24 | 40.90 | 232 | 386 | 154 | 7.8 | 319 | 399 |
| Standard iron, high $SiO_2$ | .20 | 42.36 | 198 | 396 | 198 | 10.0 | 424 | 530 |
| Standard iron, low $SiO_2$ | .23 | 42.57 | 230 | 398 | 168 | 8.5 | 362 | 453 |
| High-manganese iron, high $SiO_2$ | .34 | 42.44 | 338 | 397 | 59 | 2.9 | 123 | 154 |
| High-manganese iron, low $SiO_2$ | .40 | 42.70 | 399 | 399 | 0 | 1.0 | 43 | 54 |
| Excess limestone | .16 | 41.97 | 157 | 393 | 236 | 12.0 | 504 | 630 |
| High-silicon iron | .12 | 42.04 | 118 | 394 | 276 | 14.0 | 589 | 736 |
| High-phosphorus iron | .16 | 42.53 | 159 | 398 | 239 | 12.0 | 510 | 638 |

In discussing the effect of residual manganese Kinney says:

> It is to be emphasized that a residual manganese in excess of 0.25 per cent not only reduces the open-hearth cost per ton of ingots by decreasing the quantity of expensive ferromanganese that must be added to the heat to attain a given manganese percentage, but because of the protection it gives against overoxidation in the furnace the quality of the steel is improved. This higher-quality steel increases the percentage of merchantable product at the mills by from 1 to 3 per cent, depending on the amount that the residual manganese exceeds 0.25 per cent; and while such a saving can not be properly shown on the open-hearth cost sheet, it increases the net profits of the works as a unit.

In the larger steel plants when mixers are used, manganese removes sulphur during the time the metal is held in the mixer and in the transfer ladle. As German pig iron has a relatively high manganese content, steel containing 0.04 per cent sulphur can be made from it, although the pig iron contained as much as 0.07 per cent sulphur.

[2] Kinney, C. L., jr., "Economic significance of metalloids in basic pig iron in basic open-hearth practice": Trans. Am. Inst. Min. and Met. Eng., vol. 70, 1924, pp. 136–175.

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Sulphur control is essentially a blast-furnace problem; it can not be eliminated economically in the open hearth. High-sulphur metal is permissible when used with pig irons containing 2 per cent manganese.

There seems little doubt that the use of manganiferous iron ore is beneficial. Referring to our supply of manganese, Richards [3] suggested certain possibilities in the use of manganiferous iron ore for the production of ferromanganese. The ores containing larger amounts of manganese would have a greater potential value for this purpose than they would have for the production of high-manganese pig iron. Ores containing lesser amounts of manganese, however, may well be utilized in the manufacture of such iron.

## FERROMANGANESE AND INTERMEDIATE ALLOYS FROM CUYUNA ORES

Cuyuna ores may be divided into two classes—the so-called high-phosphorus, low-silica, or brown ores; and the high-silica, low-phosphorus, or black ores. According to Zapffe, the manganese in the reserves of the black ores is only one-eighth of that in the reserves of brown ores. Increasing amounts of the brown ores have been shipped the last few years and have been mixed with other ores to regulate the manganese content of the pig iron made in the blast furnace. The use of these ores may therefore be taken as an index of the popularity of high-manganese pig iron. Season analyses,[4] given in Table 2, indicate the composition of these two types of ore. The brown ores are high in moisture and many of them have an alumina content that is high in comparison with the silica.

### SMALL-SCALE TESTS

#### GRAVITY CONCENTRATION

Various methods have been tried in attempts to concentrate the Cuyuna ores. The Minnesota School of Mines has applied the usual gravity methods to both the black and brown ores with little success. In this connection, Newton [5] makes the following statement: "As the result of study and experimental data, it is apparent that the beneficiation of Cuyuna manganiferous iron ores by means of the present mechanical processes can accomplish but little."

---

[3] Richards, J. W., Discussion of paper by F. H. Willcox on "The significance of manganese in American steel metallurgy": Trans. Am. Inst. Min. Eng., vol. 56, 1916, p. 425.

[4] Zapffe, Carl, Manganiferous Iron Ores of the Cuyuna District, Minnesota: Am. Inst. Min. and Met. Eng. Preprint 1390–I (New York meeting, February, 1925).

[5] Newton, Edmund, Manganiferous Iron Ores of the Cuyuna District, Minnesota: Bull. 5, University of Minnesota School of Mines experiment station, 1918, p. 57.

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TABLE 2.—*Analyses of black and brown ores*

BLACK ORES

| | Iron, dry | Phosphorus | Silica | Manganese | Alumina | Moisture |
|---|---|---|---|---|---|---|
| | *Per cent* | *Per cent* | *Per cent* | *Per cent* | *Per cent* | *Per cent* |
| Algoma | 32 | 0.07–.09 | 20–23 | 17–19 | 2–3 | 7–9 |
| Clarke | 35.5 | .104 | 15.28 | 16.95 | | |
| Do | 35 | .058 | 23.86 | 10.99 | | |
| Cuyuna-Mille Lacs | 37 | .09–.10 | 18–20 | 11–12 | | 13–14 |
| Do | 36.73 | .106 | 12.93 | 17.44 | | 13.48 |
| Do | 37.46 | .106 | 7.97 | 22.01 | | 13.50 |
| Ferro | 29–32 | .07–.09 | 17–19 | 20–21 | | 7–10 |
| Gloria | 28 | .18 | 17–19 | 17–18 | | 8–9 |
| Hopkins (black ore, expected analyses in 1919) | 38 | .063 | 16.45 | 16.03 | 1.73 | 9.91 |
| Mangan No. 1, crude | 36 | .13 | 22 | 13 | 2.50 | 9–10 |
| Mangan No. 1, hand picked | 33 | .13 | 17 | 17 | 2.50 | 9–10 |

BROWN ORES

| | | | | | | |
|---|---|---|---|---|---|---|
| Arko | 41 | 0.290 | 9 | 10–12 | 4 | 14–15 |
| Armour, No. 2 | 46–49 | .18–.21 | 8.5–9.5 | 5.2–8.2 | 3.5–4.5 | 11–13 |
| Do | 46.88 | .201 | 10.43 | 7.21 | 4.07 | 11.31 |
| Hillcrest | 46–49 | .25–.28 | 6–9 | 4–6 | 3.8–4 | 8.5–9.5 |
| Huntington | 53.65 | .309 | 7.29 | 2.78 | 2.92 | 9.56 |
| Milford | 43.05 | .238 | 6.70 | 11.41 | 4.00 | 18.00 |
| Martin | 52.81 | .182 | 7.60 | 5.04 | 4.00 | 13.50 |
| Mahnomen | 50.14 | .277 | 6.97 | 4.93 | 3.24 | [1] 12 |
| Do | 46.80 | .283 | 5.48 | 8.25 | 4.20 | [1] 12 |
| Do | 43.33 | .297 | 5.10 | 11.72 | 3.25 | [1] 12 |
| Do | 41.03 | .296 | 4.43 | 13.89 | 3.25 | [1] 12 |
| Do | 36.42 | .310 | 3.90 | 18.69 | 3.20 | [1] 12 |
| Sagamore | 43 | .28 | 5 | 10 | 5 | [2] 10 |
| Do | 48 | .28 | 8 | 6.5 | 4 | [2] 10 |
| Do | 51 | .28 | 8 | 5 | 4 | [2] 10 |
| Do | 53.5 | .28 | 8 | 3.5 | 3.5 | [2] 10 |
| Sultana | 38 | .174 | 9–10 | 13.75 | 3.5 | 15 |
| Portsmouth | 46.2 | .286 | 6.44 | 6.32 | 4.52 | 17 |
| Do | 43.22 | .298 | 6.33 | 9.55 | 4.84 | 17 |
| Louise | 49.95 | .213 | 8.72 | 8.98 | 2.98 | 14 |

[1] Washed ores, 1923.

[2] Dried ores, expected analyses for 1924.

A microscopic examination [6] of specimens of brown ore shows that the quartz grains are small, ranging from 65-mesh dimensions to particles of minus 200-mesh diameters. The physical structure of the ore obviously does not favor concentration. Although concentration of these ores is desirable, the iron and manganese must be separated before they can be used in the production of ferromanganese or intermediate alloys.

In the usual methods of producing ferromanganese and spiegeleisen, the ratio of iron to manganese in the ore determines the grade of alloy that can be produced. Virtually all of the iron is reduced and 60 to 80 per cent of the manganese.

### MAGNETIZING ROAST AND MAGNETIC CONCENTRATION

Inasmuch as manganese is reduced at a higher temperature than iron, one might think that the iron can be reduced and then separated magnetically from the manganese. Newton [7] made several tests of

[6] Examination by R. E. Head, Bureau of Mines, Salt Lake City, Utah.

[7] Newton, Edmund, work cited.

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brown ores by roasting sized samples in a reducing atmosphere with pulverized charcoal and concentrating the reduced ore magnetically. The recovery of iron was low, probably indicating that the reduction had been carried beyond magnetite to ferrous oxide, which is non-magnetic; less than one-fourth of the iron and about one-half of the manganese were recovered in the concentrates. The conclusion from this work was that the iron and manganese are too finely associated to be separated magnetically.

More recently Davis [8] has made similar tests of Cuyuna ores. His work shows that the distribution of the manganese between the concentrates and tailings differs in different ores, according to whether the manganese is more closely associated with the iron or with the gangue. Table 3, calculated from the tests reported by him, shows that a fairly good separation of iron and manganese can be made in the siliceous ores. In the low-silica ore, however, the separation is rather poor; about 40 per cent of the manganese passes into the concentrate with the iron. In this case, where the iron and manganese are closely associated, the manganese shows a strong tendency to go with the iron.

TABLE 3.—*Distribution of manganese and iron in concentration tests after magnetic roasting*

| | Mesh size | Per cent by weight to concentrates | | Per cent by weight to tailings | |
|---|---|---|---|---|---|
| | | Fe | Mn | Fe | Mn |
| High-silica ore: | | | | | |
| Test No. 1 | −300 | 71.4 | 5.90 | 28.6 | 94.10 |
| Test No. 2 | −200 | 76.90 | 16.12 | 23.1 | 83.9 |
| Test No. 3 | −100 | 73.60 | 20.90 | 26.4 | 79.1 |
| Medium-silica ore (20.4 per cent): | | | | | |
| Test No. 1 | −300 | 65.0 | 14.27 | 35.0 | 80.0 |
| Test No. 2 | −200 | 75.8 | 17.34 | 24.2 | 80.7 |
| Test No. 3 | −100 | 76.2 | 19.90 | 23.8 | 78.20 |
| Low-silica ore (2.80 per cent): | | | | | |
| Test No. 1 | −300 | 87.0 | 38.75 | 13.0 | 60.6 |
| Test No. 2 | −200 | 88.7 | 35.20 | 11.3 | 63.1 |
| Test No. 3 | −100 | 91.7 | 41.10 | 8.3 | 58.7 |

## METALLIZATION AND MAGNETIC CONCENTRATION

The question arose as to whether complete metallization, rather than reduction to magnetite, would give a better separation. To obtain some light upon this problem and to determine whether results could be obtained that would warrant further experiments, a series of muffle tests was run. The charge, consisting of 100 parts of ore mixed with 40 parts of powdered charcoal, was placed in an iron crucible and covered. After heating for three hours at 900° to 950° C. in an electric muffle it was cooled quickly and weighed. The magnetic material was removed with a magnetic tube

[8] Davis, E. W., Magnetic Concentration of Iron Ore: Bull. 9, University of Minnesota School of Mines experiment station, 1921, p. 115.

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concentrator. The ore used was taken from laboratory samples collected during blast-furnace tests that are mentioned on later pages. Table 4 shows that 95 to 99 per cent of the iron was metallized. Although this work should be regarded as preliminary, a distinct tendency for the manganese to follow the iron was revealed. In tests 1, 2, 6, and 7, where the recovery of iron was good, 59 to 78 per cent of the manganese was recovered in the concentrates. In tests 3, 4, and 5, however, in which the recovery of iron was not as satisfactory, only 32, 52, and 32 per cent of the manganese were recovered in the concentrates, the greater part going into the tailings with the iron.

TABLE 4.—*Results of metallization tests of Cuyuna ore*

| Test No. | Product | Iron | | | Manganese | | Phosphorus | |
|---|---|---|---|---|---|---|---|---|
| | | Per cent in— | Weight, per cent | Per cent metallized | Per cent in— | Weight, per cent | Per cent in— | Weight, per cent |
| 1 | Ore | 39.8 | 100 | 00.0 | 14.7 | 100 | ---------- | 100 |
| | Concentrate | 60.0 | 78.5 | 95.0 | 16.6 | 59.0 | 0.35 | 45.0 |
| | Tailing | 14.9 | 21.5 | 78.0 | 10.4 | 41.0 | .38 | 55.0 |
| 2 | Ore | 40.9 | 100 | .0 | 8.2 | 100 | .31 | 100 |
| | Concentrate | 61.8 | 95.0 | 97.0 | 6.8 | 68.0 | .23 | 59.0 |
| | Tailing | 5.6 | 5.0 | 55.5 | 5.6 | 32.0 | .28 | 41.0 |
| 3 | Ore | 39.8 | 100 | .0 | 9.8 | 100 | .31 | 100 |
| | Concentrate | 64.9 | 49.0 | 97.0 | 8.4 | 32.0 | .24 | 25.0 |
| | Tailing | 19.3 | 51.0 | 89.0 | 4.9 | 68.0 | .21 | 75.0 |
| 4 | Ore | 39.7 | 100 | .0 | 11.3 | 100 | .33 | 100 |
| | Concentrate | 60.0 | 61.0 | 99.0 | 12.7 | 52.0 | .29 | 37.0 |
| | Tailing | 20.9 | 39.0 | 92.0 | 6.5 | 48.0 | .27 | 63.0 |
| 5 | Ore | 39.6 | 100 | .0 | 9.1 | 100 | .29 | 100 |
| | Concentrate | 62.3 | 41.0 | 98.0 | 10.1 | 32.0 | .24 | 20.0 |
| | Tailing | 28.1 | 59.0 | 95.0 | 6.7 | 68.0 | .31 | 80.0 |
| 6 | Ore | 45.3 | 100 | .0 | 7.1 | 100 | .59 | 100 |
| | Concentrate | 67.9 | 94.0 | 97.0 | 7.3 | 73.0 | .56 | 51.0 |
| | Tailing | 3.6 | 6.0 | 47.0 | 2.3 | 27.0 | .43 | 49.0 |
| 7 | Ore | 43.9 | 100 | .0 | 7.9 | 100 | .51 | 100 |
| | Concentrate | 69.7 | 97.0 | 95.0 | 8.6 | 78.0 | .67 | 66.0 |
| | Tailing | 2.1 | 3.0 | 67.0 | 2.4 | 22.0 | .35 | 34.0 |

NOTE.—Size of ore in tests 1 to 6, inclusive, −100 mesh; in test 7, −48+100 mesh.

The tests show that the iron and manganese are so associated in the ore that their magnetic separation is difficult whether the iron is metallized or converted to magnetite. Some idea of the closeness of the association of the iron and manganese in these ores can be obtained from Figure 1, a photomicrograph.

The problem of separating the iron and manganese is complicated by the presence of phosphorus, which seems to occur as apatite or one of its modifications. The phosphorus is so finely divided that its mechanical separation seems impossible. Concentrating tests after metallization of the iron show that the phosphorus distributes itself about evenly between the concentrates and the tailings.

John T. Jones has suggested a two-stage process for the separation of manganese and iron in manganiferous iron ores. The iron in the ore is first metallized or given a low-temperature reduction treatment. After reduction the mass is cooled, ground, and passed

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over a magnetic separator; the iron passes into the concentrate and the manganese into the tailings as manganiferous sinter. Christianson and Hunter [9] investigated the Jones process, using several ores and changing such independent variables as time, temperature, and the amount of coal used. In their preliminary experiments they determined that the best separations were made at temperatures from 1,250° to 1,300° C. About 70 per cent of the manganese passed into

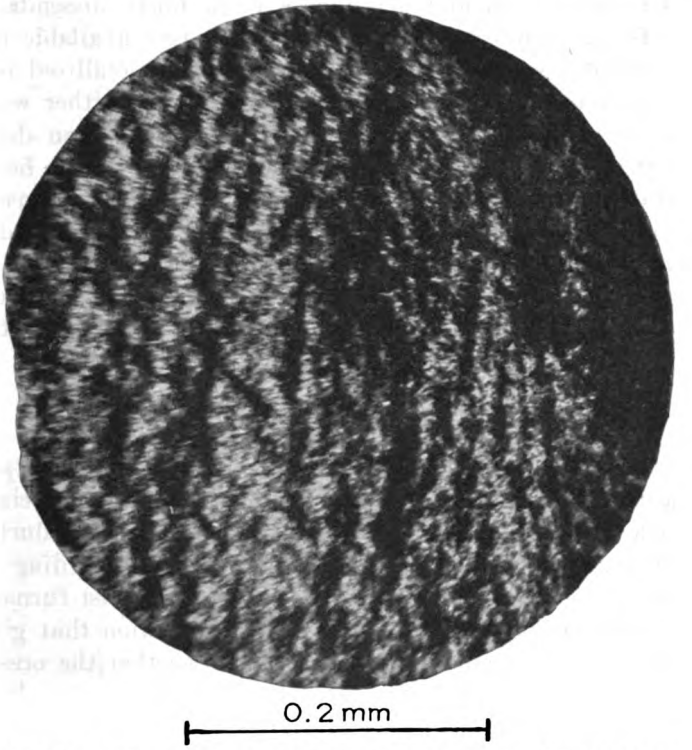


FIGURE 1.—Photomicrograph of Cuyuna ore, showing intimate association of iron and manganese oxides. Black areas represent manganese

the concentrates at a temperature of 1,050° C., but at 1,250° C. only about 6 per cent was recovered in the magnetic part of the charge. Although the amount of iron metallized was not determined, the percentage of reduction should always be high under the conditions used. It seems that the better separation at higher temperatures was due to partial fusion of the mass.

In later experiments the procedure was modified and in place of making a magnetic separation Christianson and Hunter fused the

[9] Christianson, Peter, and Hunter, W. H., "The Jones process for concentrating manganese ores; results of laboratory investigations": Bull. 173, Bureau of Mines, 1920, pp. 71–91.



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contents of the crucibles, the larger part of the metal formed a button, and the manganese passed into the slag. The fusion method suggested by the preliminary work gave more satisfactory results. By that method 93.5 per cent of the iron and 2 per cent of the manganese were recovered in the metal; 4.3 per cent of the iron and 90.3 per cent of the manganese passed into the slag.

The conclusion from this work was that it is metallurgically possible to separate iron and manganese when finely disseminated in manganiferous iron ores. From the evidence now available it seems that fusion of the mass after the iron has been metallized is necessary in order to get a good separation. Although further work will be done on methods similar to the ones that have been described, the recent efforts of the Bureau of Mines on this problem have been concentrated upon methods that involve the usual blast furnace, converter, and open-hearth processes in a somewhat modified form. Some modified form of the metallurgical procedure now in use would be more likely to be applied in commercial practice than would a new process based on new methods for metallizing the iron in the ores.

## EXPERIMENTAL BLAST-FURNACE TESTS

The behavior of a blast-furnace burden composed of 100 per cent Cuyuna brown ore has never been determined on a commercial scale. The black or high-silica ores were used commercially during the World War, and considerable data are available regarding the results obtained. It seemed desirable to make some blast-furnace tests of the brown ores to determine the slag composition that gives the best recovery of manganese and to ascertain whether the ores would offer any difficulty in smelting. It was also important to know the fuel requirements and the grade of alloy which could be made from these ores. In addition, blast-furnace tests were needed to furnish a quantity of metal for use in developing methods for separating the iron and manganese in low-grade spiegel or manganiferous pig iron. As tests with a small commercial furnace were too expensive to warrant serious consideration, the development of an experimental blast furnace for making the tests was undertaken. This development required several years and called for the exercise of much patience by all persons concerned. An experimental furnace, in addition to being a necessary adjunct to the manganese problem, also had great promise as an instrument for fundamental blast-furnace research.

After 35 tests with 16 furnaces, ranging in height from a few feet to 20 feet, had been made, the furnace whose lines are shown in Figure 2 was designed.

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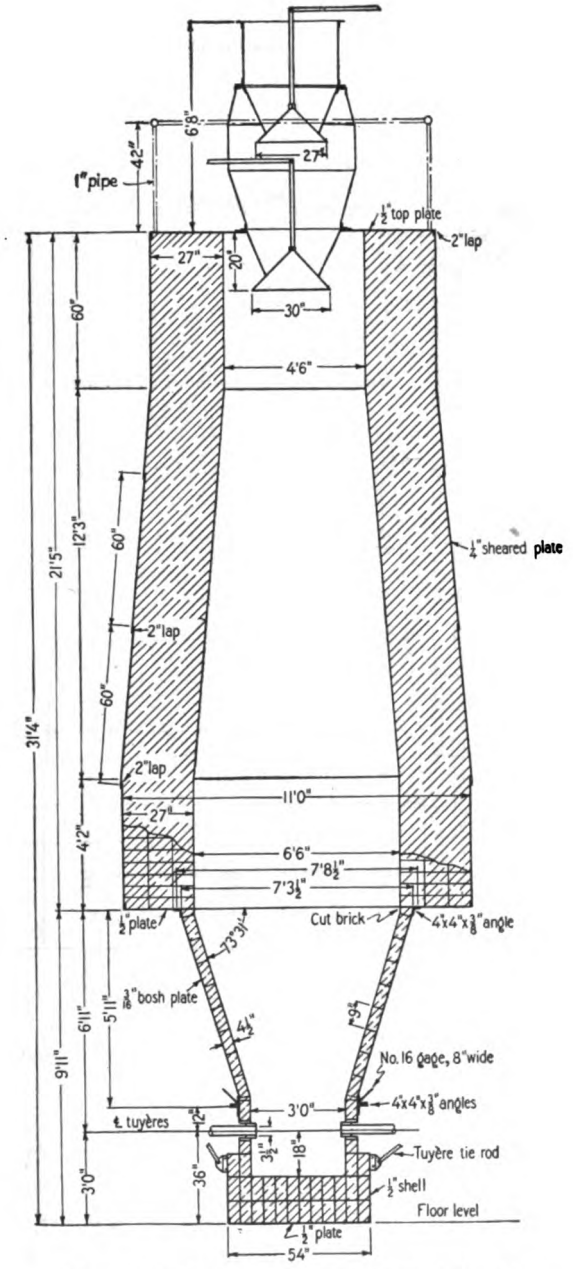


FIGURE 2.—Lines of experimental blast furnace

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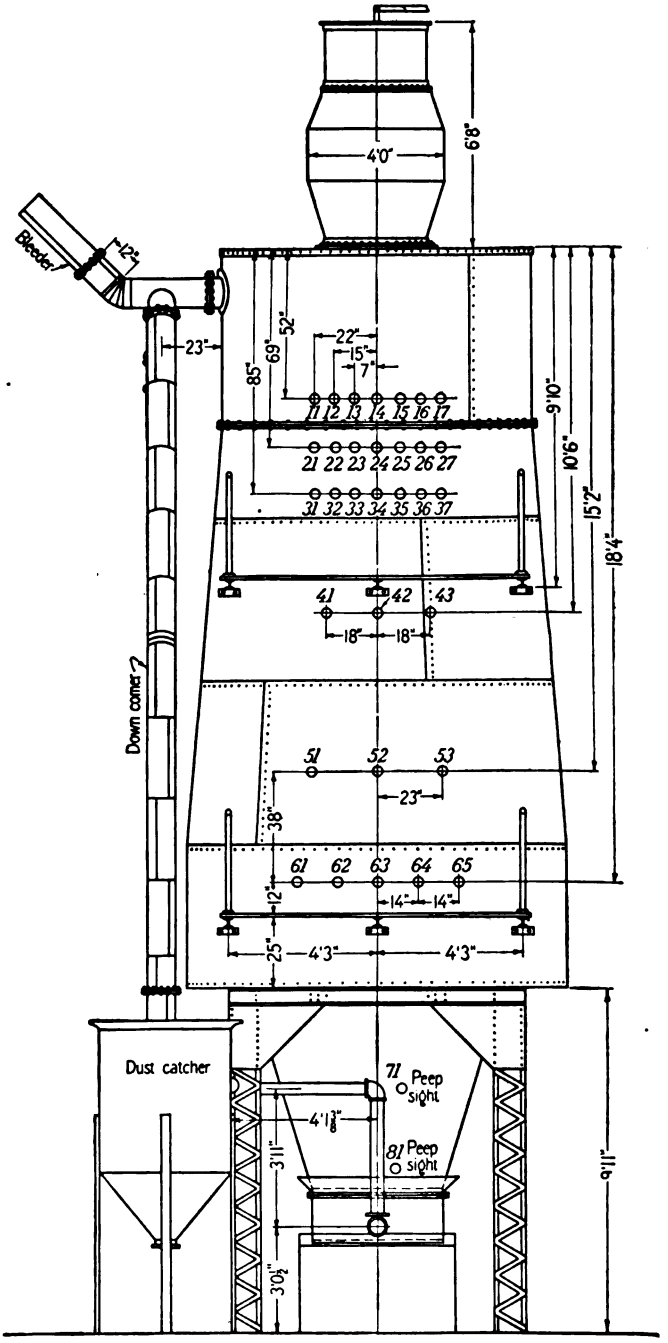


FIGURE 3.—Position of holes in lining of experimental furnace

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## DESCRIPTION OF EXPERIMENTAL FURNACE

The furnace shown in Figures 2, 3, 5, and 6 was designed by the Bureau of Mines and erected by the University of Minnesota. It is housed in a room planned for the purpose in one wing of the Minnesota School of Mines experiment station. The furnace is 31 feet 4 inches high, has a hearth diameter of 36 inches, and a capacity of 4 to 6 tons a day; Figure 2 gives its dimensions. A flexible construction was adopted for connecting the hearth and bosh in order to facilitate changes in the lower part of the furnace. As shown in Figure 5, the hearth is bolted to the bosh at the top of the tuyère breast and rests on four railroad jacks. When these jacks are lowered after the connecting bolts are removed, the hearth drops and can be moved

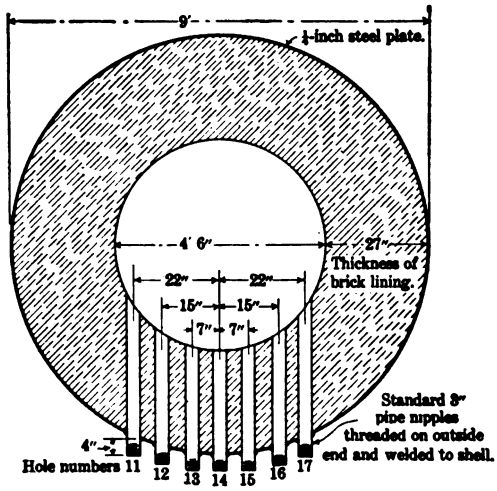


FIGURE 4.—Lines of sampling across plane 1

from under the bosh. Two plate girders riveted to the top of four columns support the furnace. This type of construction was adopted to afford more room around the bosh and hearth. On one side of the furnace are two platforms to make the test holes, shown in Figure 3, accessible.

To permit study of the reactions taking place inside the furnace, 33 holes were made through the shell and lining. As experience at other furnaces[10] had shown that the top part of the furnace was the most interesting to study with respect to reduction, the holes in that part of the furnace were at smaller intervals. In previous furnaces only one hole was made at each level, and in consequence the observations were confined to a single diameter. As Figure 4

[10] Blast Furnace and Steel Plant, January, pp. 35–37; February, pp. 98–100; March, pp. 154–158; April, pp. 246–250; May, pp. 200–204; June, pp. 274–280.

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shows, it was possible in the present furnace to sample along six chords and one diameter in the three top rows of holes. In this way a rather complete cross section of the gas phase in a plane could be had.

Unlike commercial furnaces, the experimental furnace is not charged by a skip car or buckets passed up an incline to the top of

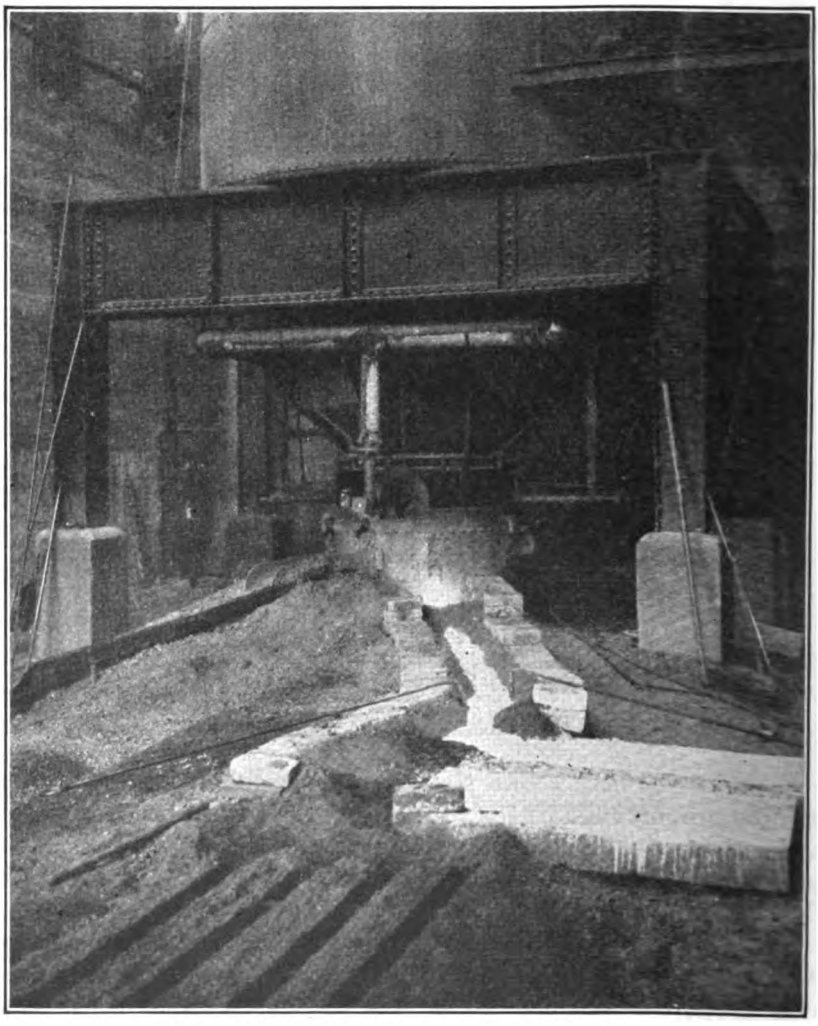

FIGURE 5.—Experimental furnace at casting time

the furnace. The raw materials are shoveled into buggies from the railroad siding and are carried by a freight elevator to the top floor of a bin tower, where the buggies are dumped into bins. Figure 7 shows how the stone, coke, and ore bins discharge on a conveyor belt. By pushing the platform scales along a track at one end of the conveyor

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belt the operator can set his scales, start the belt, and discharge the desired amount of material into the receiving box resting on the scales. The receiving box is emptied by moving the scales until the front end is even with the hole shown in the view. When the rear end of the box is raised the material discharges through the front end,

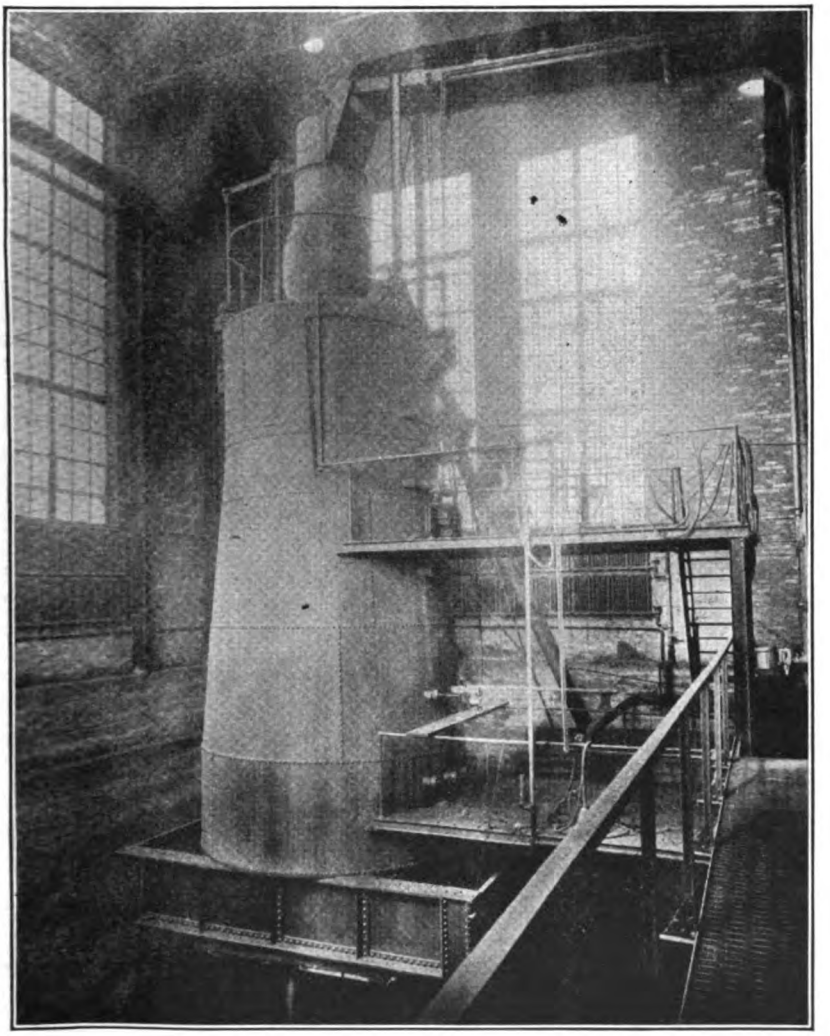

FIGURE 6.—Top part of experimental furnace

which is hinged at the top, into a hopper feeding the conveyor belt that extends to the top of the furnace. From this belt the material falls into the upper bell shown in Figure 2. A double-bell system was used to keep the top gas tight during the charging.

A positive compressor, delivering about 600 cubic feet of wind per minute, supplied the blast. Gas from the top of the furnace was

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used to preheat the air by means of a calorized pipe stove, shown in Figure 8. A blast temperature about 800° F. can be maintained with this type of stove. Four 2-inch copper tuyères delivered the hot blast to the furnace.

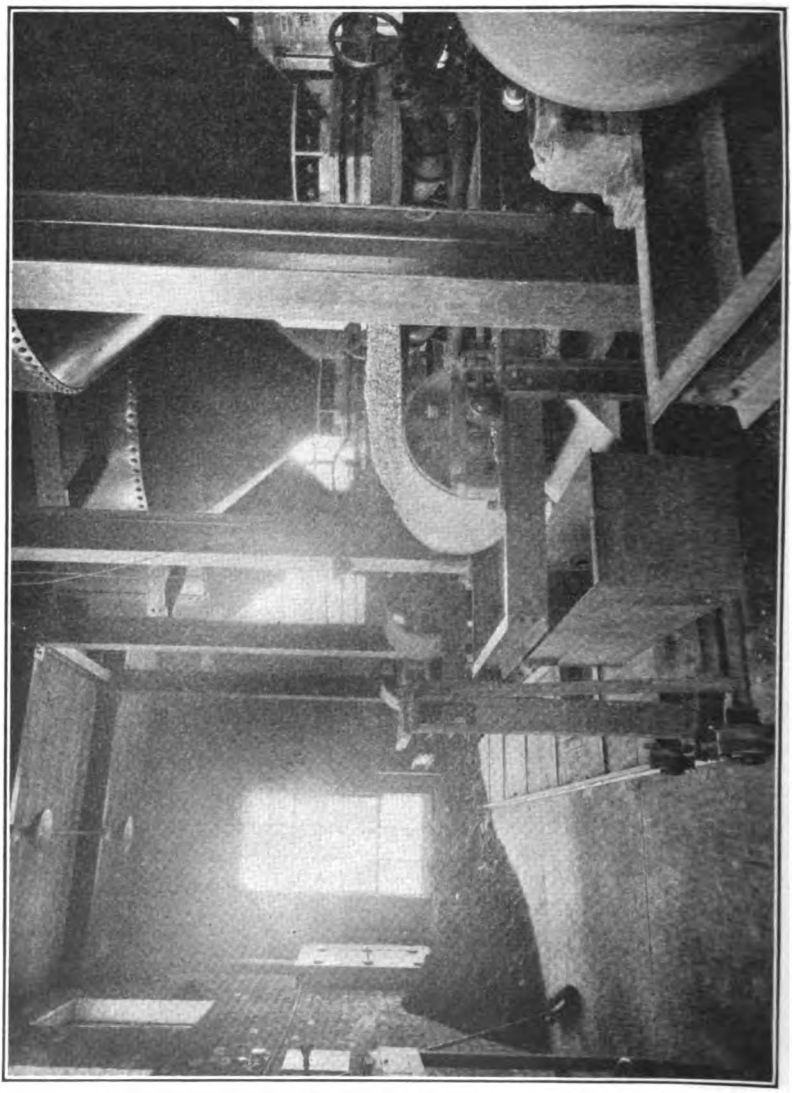

FIGURE 7.—Charging door of experimental furnace

The bosh and tuyère breast were water-cooled by external sprays. Two sprays were used on the bosh, one at the top and one about halfway between the center line of the tuyères and the top. Another spray was used on the tuyère breast. The water-cooling extended to a position 6 inches below the center line of the tuyères.

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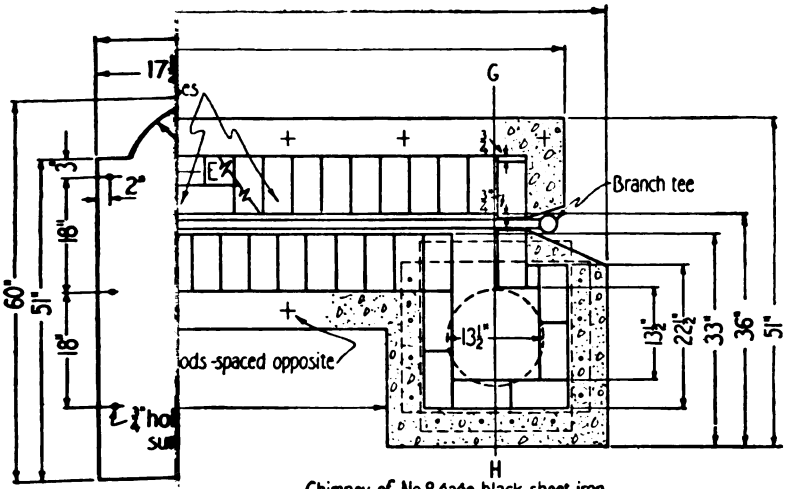
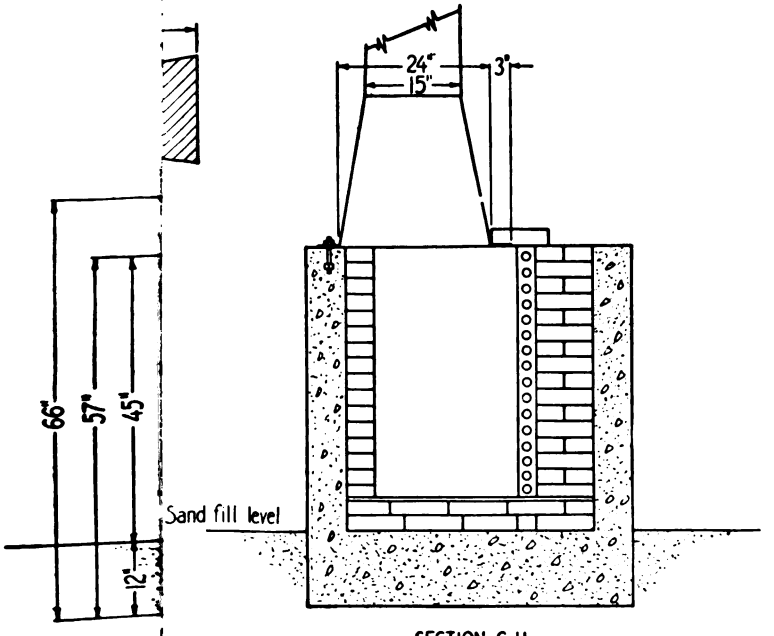



Chimney of No.8 gage black sheet iron.
½" bolt 4" long sunk in concrete to correspond with holes in chimney.




SECTION G-H

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### OPERATION OF THE FURNACE

In the operation of a furnace somewhat smaller than the one just described, the sizing of the raw materials was studied. In the experiments several sizes of ore were used to ascertain the effect of absolute size as well as the effect of the uniformity of size that results from screening. No attempt was made to size the manganiferous ore used in the present tests, the ore being charged just as it was delivered from the mine. The coke and stone were considerably smaller than that used in commercial practice, and both were sized. The coke had been passed through a 1½-inch screen and caught on an ⅛-inch screen. The size of the stone lumps ranged from ¼ to ¾ inch.

As experience had shown that experimental furnaces are very sensitive to changes in the charge, it was necessary to know within rather close limits the materials entering the furnace. As the ore was unloaded from the cars, it was divided into lots which were bedded somewhat in the manner used at western lead and copper blast furnaces. At definite intervals equal weights of the ore were thrown into a pile for sampling, and in this way representative samples were obtained for about 10-ton lots. Such careful sampling was also essential in order to make accurate balances of the materials charged.

As the coke and stone were more homogeneous than the ore, only carload samples were taken. Unusual care was observed in sampling the products—slag, metal, and gas. Each flush and cast were sampled and composite top-gas samples were taken every eight hours, in addition to samples from various levels. Analyses of raw materials and products and data on general operating conditions appear in Table 5.

TABLE 5.—*Data*[1] *on operation of experimental furnace*

ANALYSES OF RAW MATERIALS

| Coke: | Per cent | Stone: | Per cent |
|---|---|---|---|
| Moisture | 4.23 | Moisture | 0.04 |
| Volatile matter | 1.30 | CaO | 53.3 |
| Fixed carbon | 87.12 | MgO | .64 |
| Ash | 7.35 | $SiO_2$ | 1.40 |
| Ore: | | $Fe_2O_3$ | 1.08 |
| Moisture | 14.0 | $Al_2O_3$ | .83 |
| Ignition loss | 9.09 | | |
| Fe | 34.98 | | |
| Mn | 8.53 | | |
| $SiO_2$ | 6.75 | | |
| $Al_2O_3$ | 6.91 | | |
| P | .30 | | |

[1] Data selected to show relation between CaO and MnO in slag.

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ANALYSES OF PRODUCTS

[Top gas: $CO_2$, 11.03 per cent; CO, 26.47 per cent; $H_2$, 2.60 per cent; and $N_2$, 59.90 per cent.]

| Cast | Metal | | | | Flush | Slag | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | C | Mn | Si | P | | $SiO_2$ | FeO | $Al_2O_3$ | CaO | MnO |
| 39 | 3.96 | 13.00 | 0.23 | 0.60 | 50 | 28.7 | 1.25 | 15.2 | 47.7 | 4.8 |
| 40 | 5.07 | 14.40 | .15 | .64 | 51 | 27.6 | 1.10 | 14.7 | 45.3 | 6.2 |
| 41 | 4.61 | 13.78 | .42 | .63 | 52 | 27.0 | 1.03 | 15.2 | 44.0 | 8.4 |
| 42 | 4.72 | 12.62 | .19 | .63 | 53 | 30.4 | .90 | 15.3 | 41.4 | 9.1 |
| 43 | 5.08 | 13.45 | .05 | .57 | 54 | 26.5 | .67 | 14.5 | 44.0 | 11.1 |
| 44 | 4.87 | 12.72 | .09 | .67 | 55 | 26.8 | .67 | 14.7 | 41.7 | 13.4 |
| 45 | 4.80 | 12.14 | .06 | .69 | 56 | 26.7 | .80 | 15.7 | 40.8 | 12.7 |
| 46 | 5.03 | 11.68 | .08 | .59 | 57 | 26.6 | 1.46 | 14.1 | 42.5 | 12.1 |
| 47 | 4.90 | 13.13 | .08 | .68 | 58 | 28.1 | .85 | 15.2 | 41.2 | 12.6 |
| 48 | 4.71 | 14.17 | .09 | .51 | | | | | | |

OPERATING CONDITIONS, JUNE 2, 1925

| | | | |
|---|---|---|---|
| Charge: | | Total of manganese charged | |
| Ore | pounds 630 | | pounds 2,150 |
| Coke | do 360 | Manganese to metal | do 1,405 |
| Stone | do 200 | Manganese to slag | do 770 |
| Rounds per day | 40 | Manganese to metal | per cent 65.4 |
| Total coke charged | pounds 14,400 | Blast temperature | ° F 600 |
| Weight of metal | do 10,700 | Blast pressure | pounds 3 |
| Coke per ton of metal | do 3,000 | Wind per minute | cubic feet 600 |
| Slag per ton of metal | do 2,100 | Top temperature | ° F 378 |
| Coke per square foot of hearth, area per minute | pounds 1.5 | Temperature, tuyère No. 2 | ° C 1,635 |
| | | Temperature, tuyère No. 3 | ° C 1,663 |
| | | Temperature, tuyère No. 4 | ° C 1,675 |

To give a complete report of the test at this time is impossible, but the more important features can be discussed. No difficulty was experienced in operating the experimental furnace when charged with a burden of 100 per cent brown manganiferous iron ore. Most iron ores contain more silica than alumina. The alumina content of the brown Cuyuna ores, however, is high; in some lots of ore the percentage of $Al_2O_3$ present was more than double that of the $SiO_2$. As a result, the slag at times contained more than 20 per cent $Al_2O_3$. Nevertheless, the furnace ran smoothly without hanging or slipping. The high ratio of $Al_2O_3$ to $SiO_2$ necessitated great care in determining the amount of limestone in the charge, as slags high in both alumina and silica predicted furnace difficulties. When working with these slags, the limestone in the charge had to be adjusted quickly to prevent the viscosity of the slag becoming dangerously high. As shown in Table 5, more basic slags gave higher recoveries up to a certain point where the slag could be tapped from the furnace without difficulty and a clear tuyère zone could be maintained by proper removal of the coke ash resulting from combustion. Complete results of the test should disclose the type of slag which will give the maximum recovery of manganese in the smelting of these ores. The test will also show the fuel consumption and the

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grade of alloy which can be expected in practice. Although this information could be obtained at a commercial furnace, it would cost a great deal more. The experimental furnace ran for a month on the materials that a commercial furnace would use in a day.

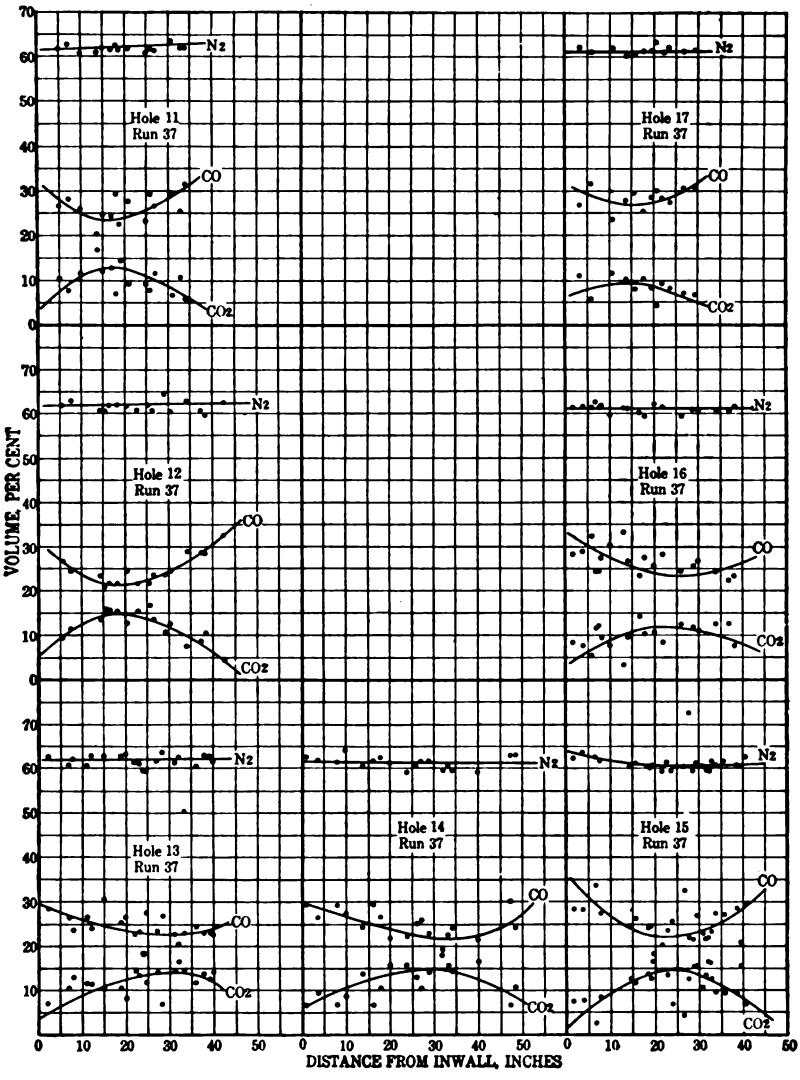


FIGURE 9.—Arrangement of curves for holes in plane 1, holes symmetrical about hole 14

As previously pointed out, the experimental furnace is equipped to permit observation of the reactions that take place within it at various levels. As the results of gas sampling across various levels have a distinct bearing on blast-furnace practice in general, as well as on the smelting of Cuyuna ores, they will be briefly discussed.

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Figures 9 to 15 give the composition of the gas across the various planes and show that the gas in the central part of the furnace is

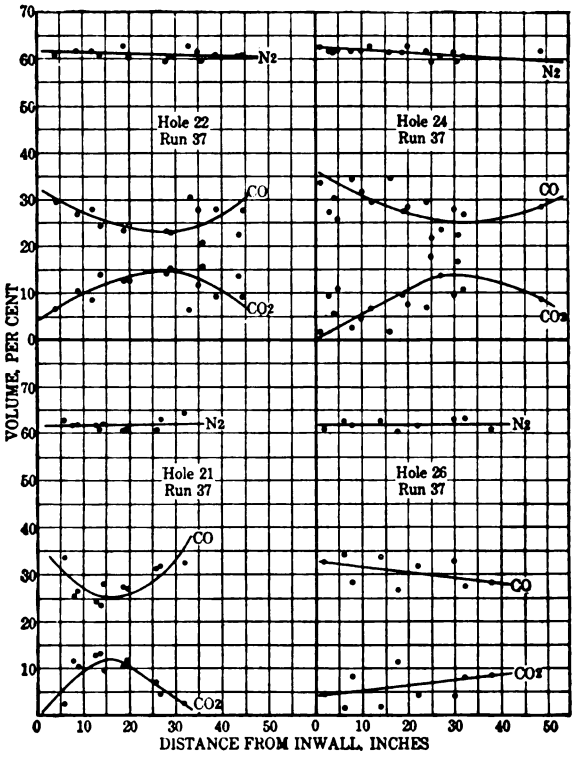


FIGURE 10.—Curves showing gas composition across plane 2, run 37

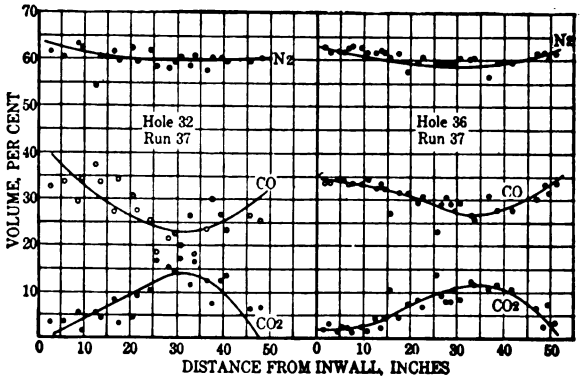


FIGURE 11.—Curves showing gas composition across plane 3, run 37

high in $CO_2$ and correspondingly low in CO. This same tendency was shown in a smaller furnace and has been reported in a series of papers [11] published in 1924.

[11] Cited under footnote 10.

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The consistent variation in the composition of the gas across five planes of the experimental furnace, as shown in Figures 9 to 15, may be the result of several causes. The low $CO_2$ content near the walls

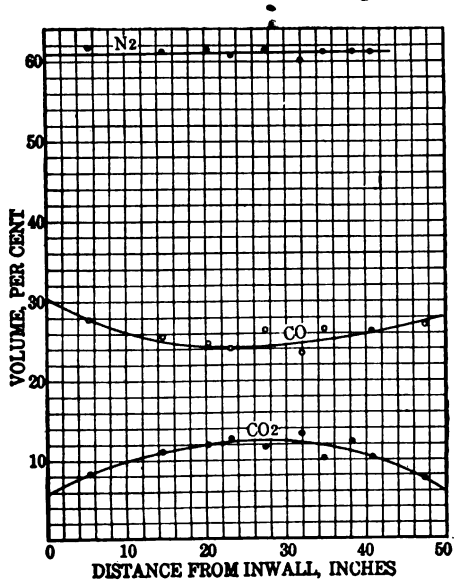


FIGURE 12.—Summary curves showing gas composition across plane 1, run 37

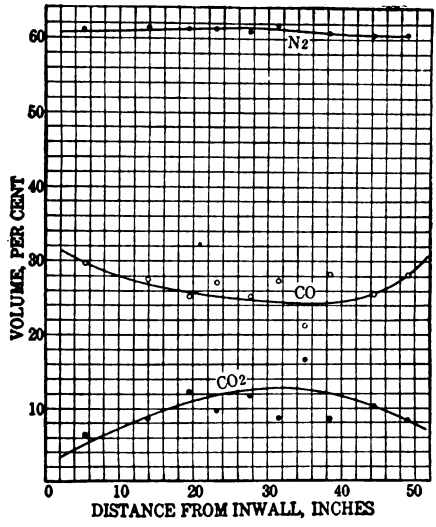


FIGURE 13.—Summary curves showing gas composition across plane 2, run 37

could be due to channeling of gas in that part of the furnace; such a channeling presupposes, however, that the charge offered less resistance to the flow of gas next to the wall than in the center of the furnace. This difference in ease of flow would be brought about

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if excess ore or the finer pieces of the charge were thrown to the center of the furnace and coarser material to the wall. Figure 2 shows that there is a foot of clearance between the larger bell and the

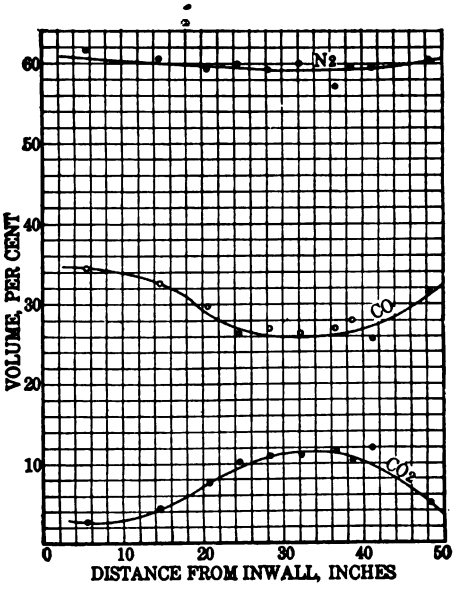


FIGURE 14.—Summary curves showing gas composition across plane 3, run 37

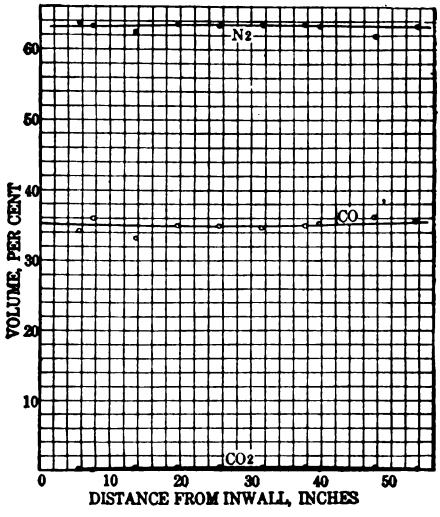


FIGURE 15.—Summary curves showing gas composition across plane 5, run 37

wall. It does not seem probable that, with the charging equipment used, an excess of fine material would be thrown to the center; on the contrary, the probable tendency would be for the finer material to be thrown to the walls, as happens in commercial furnaces.

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If the low $CO_2$ values along the outer part of the furnace were due to a wall effect, the increase in $CO_2$ would be rapid a few inches in the charge where the wall effect would be absent, but the rise in $CO_2$ is gradual.

The writers regret that there has not been an opportunity for actually observing the top distribution employed in the test. Plans have been made to build a platform on the furnace a few feet below the level of the stock line when the furnace is in operation. After a few rounds have been charged, the top will be removed and the distribution studied by observations within the furnace. The results of the gas sampling indicate an unequal distribution of the gas stream or unequal descent of the charge or both. The reader should note that if the layers formed by the charges were thicker in the center of the furnace than along the walls there would be a tendency in the center of the furnace to produce gas high in $CO_2$. This condition does not seem to have existed.

More rapid settling of the charge in the center of the furnace would produce high $CO_2$ and correspondingly low CO values there. This seems a more tenable explanation than the suggestions advanced in the preceding paragraph. The time required for changes in burden to come through the furnace was shorter than the over-all time in the furnace, and there seemed to be a marked tendency for the burden to mix inside the furnace. This tendency was evident at times when widely different burdens were charged.

## DISTRIBUTION OF GAS AND SOLIDS IN THE BLAST FURNACE

One of the striking things about the composition of gas samples removed from various points in the charge column is the wide variation in samples taken at adjacent points. This is substantial evidence that the absence of channeling by the gas stream as it ascends through the blast-furnace charge is an ideal seldom realized.

Much has rightly been said in the past about stock distribution, a matter of vital importance. Symmetrical distribution of the charge is desirable because poor distribution affects the distribution of the gas, with the result that the overburdened part of the furnace offers greater resistance to gas flow and consequently forces the gas to the part of the furnace where it is less needed. The distribution of the gas stream is controlled largely by the distribution of the charge, particularly with reference to the size as well as the quantity of the materials. The writers often regard the bottom of a blast furnace as a large gas producer. It is true that the hearth and bosh have other functions, but their primary purposes are to liberate heat in the generation of gas, which as it ascends in the furnace preheats the descending charge and removes oxygen from the iron ore. For the performance of these duties there must

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be contact between gas and solid. That the efficiency of the furnace depends greatly on the intimacy of this contact is obvious.

Segregation of fine and coarse material is detrimental to good distribution of the gas stream. Any approach to uniformity in the size of the particles in individual charges tends to eliminate this difficulty. There can be no segregation with respect to size if the size of the lumps charged is uniform. In this connection it is interesting to note that one blast-furnace operator has adopted the sizing of ore and has obtained a decided benefit thereby.

Although the distribution of the gas stream is controlled by the distribution of the charge, it seems certain that the path of the material in the furnace is affected by the burning, and consequent removal, of the coke in the lower part of the furnace. In the experimental furnace the coke was removed across the entire diameter of the hearth, but because of the effect of the bosh and of friction along the walls the charge descended faster near the center. The high $CO_2$ content of the gas in the center of the furnace, as shown in the curves, is due to the greatest movement of the charge in that part of the furnace. The first stages of reduction, which permit higher concentration of $CO_2$ before equilibrium is reached, occur here because a fresh supply of ore is present. Figures 16 and 17, by Richards and Lodge,[12] and Bernard Osann,[13] illustrate how the stock descends when combustion takes place across the entire hearth. These figures were made to represent conditions in commercial furnaces, on the assumption that the coke was removed by combustion across the entire hearth. Perrott and Kinney have recently shown that this assumption was incorrect.

The path of the materials in the experimental furnace is illustrated in the models used by Richards and Lodge, and Osann. Many influences, such as the effect of the ascending gas stream, filtering of fine ore through the charge, and the coalescing or fusion of particles were not present in the model tests. The figures are reproduced merely to give an idea of how the stock settled in the experimental furnace and have little or no practical value.

In commercial furnaces, the coke is not consumed across the entire hearth; on the contrary, Perrott and Kinney[14] have shown that combustion is confined to a region extending some 30 to 40 inches beyond the nose of the tuyères. As the writers[15] have pointed out,

[12] Richards, R. H., and Lodge, R. W., "Descent of the charge in an iron blast furnace": Trans. Am. Inst. Min. Eng., vol. 16, 1888, pp. 149–162.

[13] Osann, von Bernhard, Lehrbuch der Eisenhüttenkunde. Leipzig, 1923, p. 190.

[14] Perrott, G. St. J., and Kinney, S. P., "Combustion of coke in the blast-furnace hearth": Trans. Am. Inst. Min. and Met. Eng., vol. 69, 1923, p. 543.

[15] Royster, Joseph, "Effect of coke combustibility on stock descent in blast furnaces": Trans. Am. Inst. Min. and Met. Eng., vol. 70, 1924, pp. 224–238. Kinney, S. P., and McKenzie, F. F., "Proposed hearth and bosh construction": Iron Age, vol. 115, Feb. 12, 1925, p. 476.

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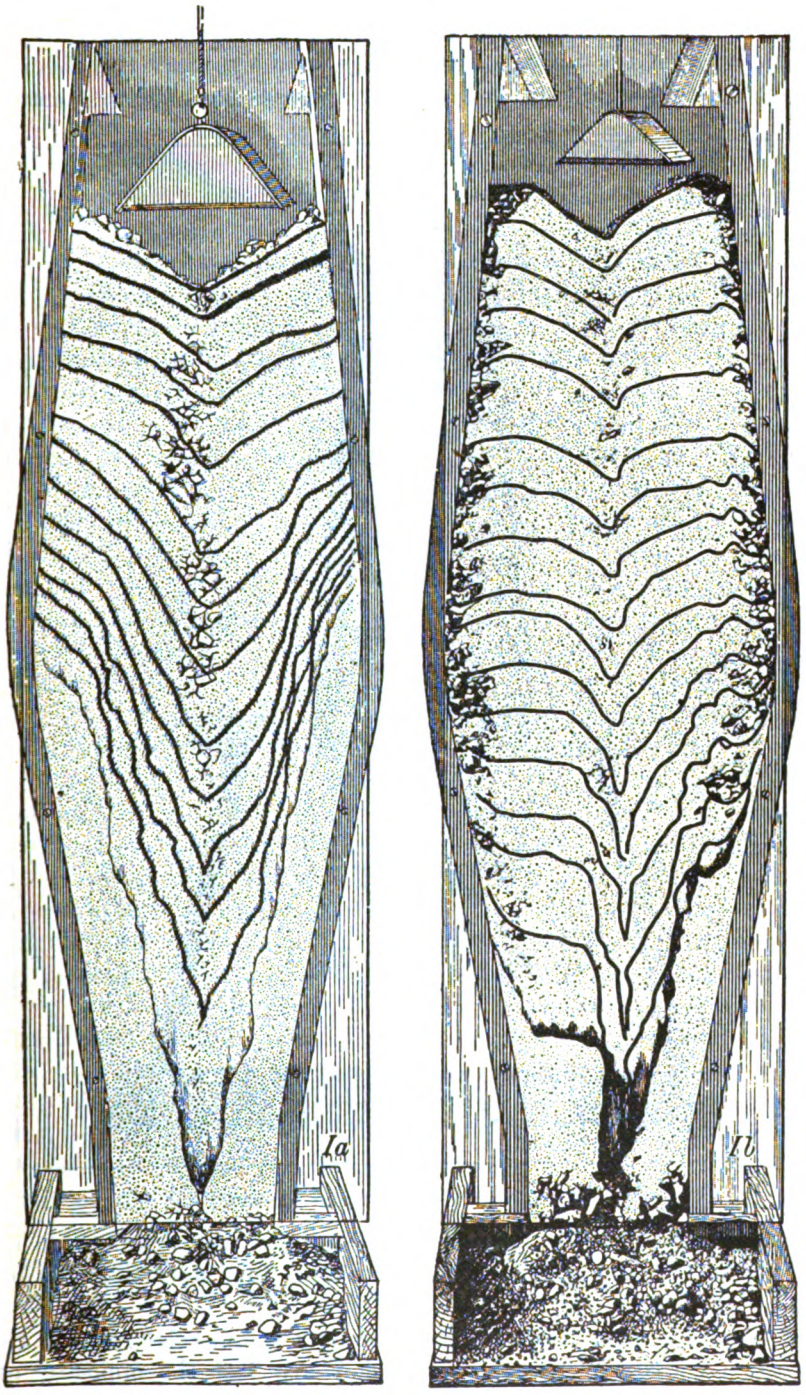


FIGURE 16.—Descent of charge in blast-furnace models used by Richards and Lodge

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localized combustion in commercial furnaces causes the stock to descend faster along the walls in the bosh and more slowly in the central part of the furnace. How high in the furnace the effect of localized combustion is transmitted remains an open question.

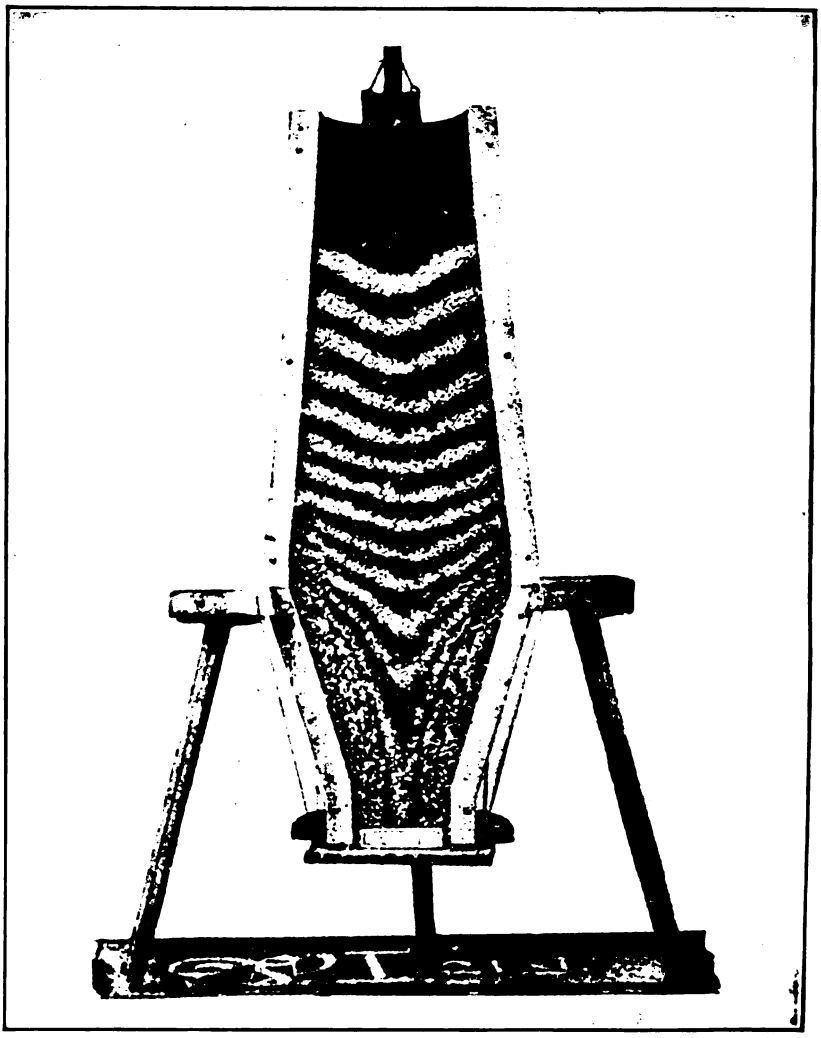

FIGURE 17.—Descent of charge in Osann's model blast furnace

Unequal descent of the charge might influence the distribution of gas, but the present opinion of the writers is that stock distribution largely controls it.

Gas samples taken from the interior of a commercial furnace by one of the writers[16] show results that are just the opposite of

[16] Kinney, S. P., Royster, Joseph, and Joseph, S. P., Combustion Reactions in an Iron Blast Furnace: Tech. Paper 391, Bureau of Mines, 1926.

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those obtained with the little furnace. In the commercial furnace the $CO_2$ in the gas was higher in the outer part of the furnace. The low $CO_2$ content in the gases removed from the central part of the commercial furnace could be caused by unequal distribution of stock or by segregation of fine material near the walls. The latter condition would deflect the gases to the center of the furnace and result in a low concentration of $CO_2$ there because of the excess of gas. There is, however, no definite evidence to show that an unequal descent of the charge might not be partly responsible for the high $CO_2$ values in the outer part of the commercial furnace. The work the Bureau of Mines has done at commercial furnaces and with its experimental furnaces indicates that the distribution of the gas depends primarily upon the distribution of the charge at the top of the furnace. Unequal descent of the charge is related to the manner in which the coke is removed by combustion in the tuyère zone.

To obtain equal distribution of the gas stream in the blast furnace becomes more difficult in smelting the fine Mesabi ores. Within certain limits the absolute size of the particles is favorable to reduction, but when extremely fine material is charged dust losses become large and the problem is no longer the time required for reduction but the insurance of contact between gas and solid. It is hoped that the work the Bureau of Mines has done will lead to information that will help to relate furnace design to the factors that control the contact between the reducing gases and the charge.

Not only has the bureau's work given fundamental data on the blast furnace and information regarding the smelting of the brown Cuyuna ores, but the runs in the experimental furnace yielded 134 tons of metal which are now available for a study of the problem of separating the iron, manganese, and phosphorus. If their separation can be made, the production of a higher-grade manganese alloy low in phosphorus will be possible. The manganese content of the metal on hand ranges from 2 to 15 per cent; the phosphorus is uniformly high, about 0.6 per cent. Sulphur is present in negligible quantities.

A possible means of producing metal having a higher ratio of manganese to iron and a smaller content of phosphorus is through the selective oxidization of these elements, which may take place in any of the present steel-making processes. Slag resulting from the blowing of low-grade spiegeleisen in a Bessemer converter or from oxidizing spiegel in the open hearth can be used as an artificial ore to produce ferromanganese in the blast furnace or electric furnace.

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TABLE 6.—*Analyses of various manganiferous Bessemer pig irons, and of resulting baths and slags*

| Name of works | Character of sample | Time to beginning of boil | Time of blowing after which samples were taken | Iron contained— | | | Composition of Bessemer slags | | | | | | Silicate grade |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | C | Si | Mn | FeO | MnO | MgO | CaO | $Al_2O_3$ | $SiO_2$ | |
| | | *M. s.* | *M. s.* | | | | | | | | | | |
| Langhytt'n | Pig iron | | | 3.94 | 1.14 | 0.64 | 0.90 | 0.58 | 6.75 | 32.07 | 12.90 | 46.50 | 1.36 |
| | Bessemer bath | 2 45 | 2 15 | 4.20 | .04 | .12 | 34.72 | 13.95 | .24 | 2.60 | .78 | 48.76 | 2.16 |
| | | | 4 30 | 1.10 | .03 | .12 | 21.08 | 15.48 | .30 | 3.25 | .98 | 59.82 | 3.29 |
| | | | 5 30 | .05 | .01 | .06 | 35.82 | 12.29 | .21 | 2.35 | .72 | 48.48 | 2.19 |
| Sandviken | Pig iron | | | 4.49 | 1.08 | .83 | .90 | 3.40 | 9.03 | 31.80 | 1.56 | 51.00 | 1.83 |
| | Bessemer bath | 2 30 | 3 00 | 3.87 | .03 | .11 | 20.24 | 23.90 | (1) | .44 | 1.84 | 53.44 | 2.63 |
| | | | 5 00 | 1.30 | .03 | .09 | 17.04 | 22.80 | | .46 | 1.94 | 57.80 | 3.10 |
| | | | 5 45 | .33 | .02 | .07 | 18.48 | 22.23 | | .36 | 1.58 | 55.76 | 2.99 |
| Nykroppa | Pig iron | | | 4.35 | .88 | 1.15 | .77 | 2.14 | 22.18 | 21.79 | 5.83 | 47.16 | 1.36 |
| | Bessemer bath | 1 30 | 2 30 | 4.10 | .10 | .15 | 13.50 | 29.76 | .23 | .42 | 2.28 | 53.26 | 2.59 |
| | | | 4 30 | 1.00 | .05 | .15 | 9.54 | 23.70 | .28 | .60 | 3.90 | 62.34 | 3.48 |
| | | | 6 30 | .08 | .04 | .08 | 30.60 | 21.39 | .21 | .38 | 2.14 | 44.52 | 1.85 |
| Bangbro | Pig iron | | | 4.00 | 1.02 | 1.83 | 1.80 | 5.44 | 10.88 | 27.22 | 3.86 | 50.20 | 1.72 |
| | Bessemer bath | 2 45 | 3 00 | 4.30 | .03 | .22 | 14.20 | 26.31 | .22 | .62 | 2.86 | 55.26 | 2.76 |
| | | | 4 45 | .90 | .03 | .12 | 18.52 | 31.01 | .14 | .38 | 2.70 | 47.20 | 2.01 |
| | | | 5 45 | .10 | .03 | .09 | 31.19 | 25.43 | .11 | .32 | 2.24 | 40.50 | 1.56 |
| Westanfors | Pig iron | | | 4.22 | 1.06 | 5.12 | .70 | 11.16 | 18.37 | 19.10 | 4.36 | 46.72 | 1.42 |
| | Bessemer bath | 2 30 | 4 15 | 4.20 | .43 | 3.26 | 4.20 | 46.38 | .54 | 1.26 | 3.08 | 45.87 | 1.83 |
| | | | 8 35 | 1.30 | .12 | .85 | 6.24 | 52.26 | .29 | .70 | 2.49 | 39.07 | 1.42 |
| | | | 9 20 | .55 | .07 | .43 | 9.45 | 48.92 | .46 | 1.00 | 2.94 | 37.63 | 1.34 |

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In the Bessemer process as conducted in Sweden, manganese plays an important part. In the usual practice of Swedish blast furnaces basic slags are used. These help to eliminate sulphur and to produce a pig iron high in manganese and low in silicon. The manganese is a source of heat in the converter, and enough of it is present at the end of the blow to obviate the use of any ferromanganese or spiegeleisen to deoxidize and recarburize the steel. The blow is not continued until the carbon flame drops, as is customary in this country, but is interrupted at a point where the carbon has been reduced to the limit desired. Although inherent difficulties are recognized when much manganese is present in the converter, iron containing as high as 5.12 per cent manganese has been used regularly in Swedish practice. Table 6, prepared by Akerman,[17] shows the influence of manganese upon the Bessemer process.

The analyses taken from the practice at Westanfors show that a pig iron containing 5.12 per cent manganese produces a slag containing 9.45 per cent FeO, 48.92 per cent MnO, and 37.63 per cent $SiO_2$. It is obvious that silica has been picked up from the lining. The oxidization of the manganese and silicon contained in the iron would give a slag in which the manganese and silica would have a ratio of about 3 to 1. A corrosive effect of manganese upon an acid lining is to be expected, but this effect can be greatly reduced by the use of a basic lining.

Ferromanganese containing 75 per cent manganese could be produced by using this slag as a charge in a blast furnace if the blast furnace could recover 80 per cent of the metal, but an 80 per cent recovery would require less contamination of the slag by silica from the lining than in the Swedish practice quoted. Thus the development of a suitable converter lining becomes a major problem. The ratio of iron to manganese in the slag will depend upon the amount of manganese in the metal. Converter practice would be characterized by slow blowing, small heats, large tuyère area, and a suitable lining. Temperature of the bath would be difficult to control. The superior quality of the steel made from blowing high-manganese metal would compensate for the slower blowing.

The presence of phosphorus complicates the utilization of the Cuyuna ores. As the large deposits are of the high-phosphorus, low-silica type, their successful utilization will depend on the eliminating of phosphorus. This elimination will require either a converter process, as in Thomas-iron practice in Europe, or a duplexing process using a converter and an open hearth. If a duplex process were used, the brown ores might be smelted in the blast furnace, and the alloy produced blown in a basic-lined converter to give a rich manganifer-

[17] Akerman, Richard, "The Bessemer process as conducted in Sweden": Trans. Am. Inst. Min. Eng., vol. 22, 1894, pp. 265–289.

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ous slag and high-phosphorus, low-sulphur metal. This converter slag would be used as an artificial ore for producing ferromanganese. The blown metal could be dephosphorized in an open-hearth furnace, yielding a steel extremely low in sulphur. A separation of the manganese and phosphorus could also be made in a double open-hearth treatment, the manganese being removed as slag from an acid-lined furnace, and the phosphorus eliminated in a basic furnace. During the World War furnaces in Belgium [18] were able to produce an intermediate alloy by smelting slag from old slag dumps.

## USE OF LOW-GRADE SPIEGEL

At several plants in this country low-grade spiegeleisen is used to recarburize and deoxidize rail heats. This practice would furnish a market for Cuyuna ores were not their phosphorus content so high. Low-carbon steel can not be made by this method, but a considerable tonnage of steel containing 0.3 per cent and more carbon is produced annually. If the trouble due to the phosphorus can be overcome by mixing brown ores with black low-phosphorus ores, or if phosphorus can be eliminated in a basic electric furnace, the use of manganiferous ores can be increased.

At present not enough data are available for determining the most efficient way of utilizing these ores. More information on their present use in the blast furnace is needed. The recovery of manganese in the pig iron and the extent of improved desulphurization should be determined. Although the practice of using high-manganese pigs to obtain residual manganese seems to be increasing, there are still differences of opinion as to what benefits are realized. The information needed must be sought through the cooperation of steel companies and blast-furnace operators, inasmuch as they alone can furnish comparative data. The development of new methods for utilizing the Cuyuna ores must depend on experiments. The first step in the process, the production of low-grade spiegel in the blast furnace from 100 per cent Cuyuna ores, has been completed. Small-scale converter and open-hearth tests are now in progress. Some phases of the problem can be studied on a laboratory scale. It was for the purpose of determining more accurately the technologic problems and the economic conditions that affect the use of these ores that this investigation has been undertaken.

[18] Greiner, Leon, "The Belgian iron and steel industry during the German occupation in the Great War": Jour. Iron and Steel Inst., vol. 99, 1919, p. 37.

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